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ABSTRACT

Problem solving is an essential skill in the study of genetics. Genetics problems have traditionally come from laboratory activities and textbook situations. Recently computer-based problems have been available to complement these standard sources. This report focusses on the use of computer-based problems in the study of genetics. Discriptions and comparisons of textbook, laboratory, and computer-based problems are stated and an explanation is given of how college students (N=68) performed in completing and understanding computer-based problem-solving tasks. Examples of problems involving dominance and linkage concepts are presented. The study results suggest that computer-based problems can encourage productive rather than reproductive thinking and thus facilitate meaningful rather than rote learning of genetic concepts. It is believed that this type of learning experience confronts student misconceptions, identifies inadequacies in student problem-solving skills, and provides a productive context in which students can develop and refine their skills. A 23-item list of references is appended. (ML)

COMPUTER SIMULATION & PROBLEM SOLVING IN GENETICS

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Genetics, an integral component of the biological sciences, embodies concepts and processes of both academic interest and also of relevance to everyday life. This is especially apparent as the new - for example, DNA technology - is blended with the old - for example, classic techniques of linkage analysis - to generate advances in the current detection and potential treatment of inherited disorders.

Students of genetics are typically exposed to different kinds and amounts of teaching/learning experiences that include attendance at lectures, participation in tutorials and discussion sessions, involvement in laboratory activities and field work, completion of text readings and sets of assigned problems. The nature and sequence of these experiences in a course of study is intended to contribute to the development of students' understanding of the concepts of genetics and of their skills in the processes of that discipline. In different courses of study in genetics, some kinds of experiences may have a limited representation, but the inclusion of experiences that are directed towards the development of problem-solving skills is a common element.

Skill in problem solving is accepted as a valuable goal of the educational process. This skill can be addressed in a domain-independent context, and the work of some researchers has focussed on the problem solving in this general context (e.g., Simon 1980, Salmina & Sorhina 1982). Problem solving can also be addressed in discipline-specific contexts, and this has been done in several areas, including physics (e.g. Larkin 1980) and genetics (e.g. Stewart 1983).

For the successful application of problem-solving skills in a discipline-specific context, learners must have a mastery of the knowledge base and of the investigatory armory of that domain, as well as possessing general problem-solving knowledge. It follows that analysis of students' performance on problem solving tasks can act as an indicator of their conceptual understanding and also of their skills in both the domain-specific and general processes of problem solving. This premise provides the basis for the common use of genetics problems in assessing students' understanding of concepts in that domain. However, studies of student performance in genetics problem solving reveal that solution of genetics problems does not necessarily reflect meaningful understanding of the concepts embodied in the problems (Stewart & Dale 1981, Longden 1982).

Where genetics problems are accessible to solution by application of the 'right' algorithm, success by some students in solving this type of problem simply measures correctness of their choice of algorithm, and provides litle or no indication of their understanding of the genetic concepts. This lack of correspondence between conceptual understanding and the success in solving typical genetics problems provides a motive for attempting to extend the learning experiences of genetics students to include problem-solving tasks in which meaningful understanding of the relevant concepts is a necessary condition for solution.

Problem-Solving Tasks in Genetics

The following section provides a brief analysis of the tasks that have traditionally provided the substance around which students' problem-solving experiences in genetics have been centered. The problem-solving tasks have been based on two sources:

* the 'pen-and-paper' problems exemplified by the problems found at the end of relevant chapters in textbooks - these will be referred to as textbook problems;

* the 'hands-on' problems that are incorporated into laboratory investigations - these will be referred to as lab. problems.

While genetics students can be, and are, exposed to problem-solving tasks via their laboratory activities, because of the demands (e.g. time, space, cost) of the hands-on situation, the majority of problem-solving tasks undertaken by students are of the textbook type.

Hands-on laboratory activities can differ in the quality of the problem-solving tasks they provide; this depends on whether or not the following elements are prescribed or are open to learner choice or control:

- aim
- materials
- methods
- answer(s)

Not all laboratory activities qualify as problem-solving tasks; those in which all the above-mentioned elements are perscribed should be classified as confirmatory exercises, rather than investigatory or problem-solving tasks. In laboratory activities of this type, the focus is not on problem solving, but is on the development of other skills such as technical or manipulative skills.

Laboratory activities in genetics can vary with regard to their degree of openness. However, at high school and undergraduate levels, a common type of laboratory activity is one in which the aim, the materials, and the methods are prescribed, and the only open element is the answer. Students engaged in such activities manipulate given materials through a given experimental method to generate a body of data from which they derive a conclusion or answer. This type of laboratory activity provides students with one kind of problem-solving task in their study of genetics. The pressures on available time can produce a bias towards laboratory activities that are 'time efficient' and 'successful', that is, activities in which execution of the prescribed methods has a high probability of producing the result expected and desired by the instructor.

It is not unexpected that there is a relative paucity of laboratory activities with a higher degree of openness that encompasses materials and/or methods. This is a consequence of the real constraints - e.g., safety requirements, time demands, staffing demands, logistic considerations - of laboratory-based investigations for groups of students.

Textbook problems in genetics typically provide learners with a clear statement of aim. In many instances, this aim is precisely focussed:

EXAMPLE 1 Which is the dominant trait?
EXAMPLE 2 What kinds of offspring and in what proportions are expected from this cross?

In other cases, the aim provides less specific direction:

EXAMPLE 3 Suggest an explanation for this observation?

Problems are usually physically arranged in association with chapters in textbooks or temporally arranged in association with a topic of study. In consequence, even problem aims such as example 3 above, are usually effectively narrowed in focus to the concepts presented in the current chapter or topic of study.

A key feature of textbook problems is that they provide learners with data that may be regarded as representing the outcome of execution of appropriate methods on given materials:

EXAMPLE 1 Crosses of blue plants produce only blue offspring, but crosses of green organisms sometimes give only green offspring, but in some cases produce some green and some blue offspring.
EXAMPLE 2 The test cross of an organism heterozygous for both wing shape and body color was carried out.
EXAMPLE 3 A female animal with genotype <u>AaBb</u> is crossed with a double recessive male (<u>aabb</u>). Their progeny includes 442 <u>AaBb</u>, 458 <u>aabb</u>, 46 <u>Aabb</u>, and 54 <u>aaBb</u>.

In textbook problems, data are immediately available, but in laboratory problems, the learner must actually process given materials through prescribed methods and generate experimental data. In both cases, however, the data are constrained - in the case of the textbook by what is given, and in the case of the lab. activity by the prescribed methods. The lab. data are subject to error and may be confounded by extraneous information that learners judge to be relevant. In extreme cases, because of mishap, malfunction, or technical difficulty, learners may be frustrated in their efforts to generate experimental data. The data in textbook problems are not subject to distortion or loss from the factors identified above.

Other characteristics of the data given in textbook problems may be identified. In particular, the data are relevant to the problem situation, they are parsimonious in that they include no unnecessary or irrelevant information, and they provide the critical information that is required and sufficient for solution of the problem, although in some cases, the data must first be transformed and manipulated. For the lab. problem-solving task, provided the performance of the given experimental methods on the given materials is not confounded by mishap, the data that are generated share these same characteristics.

The concepts that are encompassed in any group of textbook problems tend to be restricted to a narrow and sharply delineated range. This 'filtered' presentation belies the complexity of the genetics of the real world. If concepts are only ever presented to and explored by students in narrowly-defined compartments, this may result in a situation in which the students have many 'chapter-bound' conceptual frameworks, each discrete and without links to the others.

The features of the textbook and the lab. problems to which learners are commonly exposed in their study of genetics may be summarised as shown below:

	TEXTBOOK PROBLEM	LABORATORY PROBLEM
AIM	given	given
MATERIALS & METHODS	implicit or explicit in given data	prescribed
DATA/RESULTS	prescribed	generated from prescribed methods
QUALITY OF DATA	relevant, parsimonious, and sufficient for solution	potentially as for textbook problem but can be confounded
ANSWER	open	open

Extending the Problem-Solving Process

Simon (1978) makes a distinction between well-structured problems and fuzzy or ill-structured problems. The former are clearly formulated, and principally require the information contained in the problem, supplemented by procedural knowledge, such as an algorithm, for their solution. Ill-structured problems are not clearly formulated, and lack a procedure that guarantees a correct solution. Textbook problem-solving tasks of the type shown above, and laboratory problem-solving tasks, in which the availability of data is not confounded by procedural mishaps, largely qualify as well-structured problems. The genetics student who is faced with a well-structured problem, for which relevant and parsimonious data sufficient for its solution are given or prescriptively generated, may be likened to a hiker who is given a map, a target, and is also started off on the route. Regardless of the hiker's understanding of map reading, there is a reasonable expectation of reaching the target, even though the shortest route to the target may not be followed, and some incorrect paths may be taken at branch points on the way. Success is based on application of the rule: 'Follow this route. On error, return to branch point'.

Two kinds of thinking in problem solving, namely productive and reproductive thinking, have been identified by Greeno (1973). Reproductive thinking is involved when the solution plan for a problem essentially entails an appropriate algorithm retrieved from long-term memory. In contrast, productive thinking is involved when the solution plan for a problem includes reorganisation of the elements of the problem and the identification and addition of new information. The fact that students of genetics are able to solve textbook problems while lacking an understanding of some key concepts indicates that they are using reproductive thinking in problem-solving and are applying rules that have worked for like problems.

Frederiksen (1984) has identified a class of problems that he terms 'structured problems requiring productive thinking'. The incorporation of problems of this type into the learning experiences of genetics students would complement the use of well-structured problems that are accessible to solution by identification and application of an algorithm. Computer-based problems drawing on appropriate software have the potential to provide problems of the type that require productive thinking. The potential of appropriate software in a well-designed setting to create an environment in which learners are able to develop and organise their own knowledge structures has been discussed by Hartley (1985).

Computer-based problems may be derived from simulations that provide learners with choice of available procedures and control of sequences. Simulations can vary in this regard; for example, CATLAB (Kinnear 1982b) and BIRDBREED (Kinnear 1982a) provide a high degree of user control as well as incorporating a breadth of concepts in transmission genetics. Both programs have been used in studies of problem solving and conceptual development in students of genetics (Kinnear 1983a, 1983b, Kinnear et al. 1982, Peard 1983).

There is a qualitative and key difference between computer-based problems and other problems in genetics. In the former, on the basis of a statement of the problem, learners actively engage in the identification of a solution plan, and initiate a sequence of collection of learner-selected data to implement this plan. In contrast, the latter typically either provide data or allow them to be generated via prescribed methods. The computer-based task has the potential to expose genetics students to problem-solving experiences that involve data acquisition, hypothesis generation, data evaluation, and hypothesis evaluation and which are typical of clinical medical education (Elstein et al. 1979). To return to the analogy of the hiker, the task faced by students who undertake computer-based problems is like that of a hiker who is given a target and a map. Success in attaining the target is dependent of the hiker's understanding of concepts, such as gradient, elevation, scale, and their symbolic representations, and on the hiker's skill in map reading and interpretation.

Analysis of student performance on computer-based problems can elucidate aspects of students' problem solving (Kinnear 1983b). The importance for the educational process of understanding the problem representations, solution strategies, and control mechanisms of learners and experts has been widely stressed (e.g., McGaw & Lawrence 1984).

This paper reports on problem solving in a group of genetics students; in particular, on the use of computer-based problem solving tasks in elucidating aspects of their problem-solving strategies, and on the impact of these problems in identifying misconceptions and in contributing to meaningful learning.

MATERIALS & METHODS

The subjects of this study were College students (n = 68) who comprised second-year students enrolled in an introductory genetics subject of one term's duration; all had previously completed a prerequisite subject in general biology that included a four-week module of basic genetics. All students were familiar with the use of the microcomputer, as use had been made of it in several of their first-year studies.

The dominance problem-solving task

For this task, students were given two problems. The first problem was selected from a bank of five typical textbook problems, an example of which follows:

D1. The following observations were made in a species of flowering plant -

Crosses of blue by blue always gave blue-flowered progeny; crosses of purple by purple in some cases gave all purple-flowered progeny, but in other crosses produced both purple progeny and blue progeny in proportions of about 3:1.

Which, if either, is the dominant trait?

All students completed this problem and submitted a record of their working and of the time taken for the task before undertaking a second problem.

The second problem was a computer-based problem drawn from a bank of ten problems derived from the BIRDBREED program. Each problem involved the same basic concepts of dominance and recessiveness. An example of such a problem follows:

D2. Breeding group A includes sky blue birds and light green birds. Assuming a single gene is involved, which,if either, is the dominant trait?

Students again submitted their working and a record of the time spent on problem 2. In a brief questionnaire, students were asked to indicate (i) which in their view was the easier problem, and why, and (ii) whether or not, the computer-based problem assisted their understanding of genetics.

The linkage problem-solving task

For this task, students were given three problems; one was a textbook type problem, and the remainder were computer-based.

For the first problem, students were given the sheet shown below and asked if they could solve the problem, and if so, how confident were they of their answer.

L1. One gene in <u>Drosophila</u> xxxxxxxx xxxx xxxxx, xxxxx xxx xx xxxxxx xxxx xx xxxxx. xxxxxxx xxxx xxxxxxxx xxxx xxxx, xxxxx xxx xx xxxxxx xxxxxx xx xxxxx. x xxxx xxxxx xx x xxx xxxxxxxxxxxx xxx xxxx xxxxx xxx xxxx xxxxx xxx xxxxxxx xxx.
xxx xxxxxxx xxxx:

xxxx, xxxxxx	236
xxxx, xxxxxxxx	253
xxxxx, xxxxxx	50
xxxxx, xxxxxxxx	61

Are the two genes linked?

The other problems given to the students comprised the following computer-based problems which were to be investigated using the program CATLAB:

L2. In cats, one gene controls coat color and has the alleles, orange (D) and cream (d). A second gene controls pattern of striping and has the alleles, blotched (T) and mackerel (t). Are the two genes linked?

L3. Another gene in cats has the alleles all-white (W) and not all-white, that is colored (w). Is this gene linked to the gene that controls the pattern of striping?

DISCUSSION & RESULTS

The dominance problems

Based on the information supplied by the students, the mean time spent on textbook problem D1 was 3.8 minute, with a range of 2 to 7 minute. The mean time for the computer-based problem was 42 minute (range 15 to 70 minute). All students obtained the correct solution to problem D1. However, two students failed to reach any conclusion in problem D2, and 12 students reached an incorrect conclusion.

It was not unexpected that the computer-based problem took longer because of the time required to formulate a solution plan, and the time required to generate and interpret the data. What was unexpected was that almost three-quarters (73.5%) of the group identified the computer-based problem as easier than the textbook problem. Clearly the students did not relate time spent to perceived difficulty of the task. The reasons stated by students for their nomination of the computer problem as 'easier' included the following:

'It was easier because I could visualise what I was doing.'
'We were able to see outcomes of what we were doing.'
'Finally we were able to see in visual form the effects of different modes of inheritance.'
'Visual representation assisted my understanding of the principles.'
'With the computer I was able to observe a group of birds and explain the reasoning behind it (opposite to what is usually taught)'

The most common feature in the students' explanations for their choice of the computer problem as easier than the corresponding textbook problem was reference to aspects of visualisation - see, observe, visualise. This may indicate that more meaningful learning of the concepts resulted from the reflection and productive thought involved in the computer-based problem, and that overall students find a task to be 'easier' if it results in more meaningful learning.

The two students who failed to reach any conclusion provide a contrast. One student appeared to fixate on the process of setting up crosses and producing offspring, and failed to gain insight into the problem. This student's worksheet showed almost no annotation. Later discussion with the student revealed that the diffi ulty lay with the process of problem solving rather than any difficulty with the genetic concepts involved.

The second student was unable to reach a conclusion because of a misconception regarding dominance. This student's concept of dominance had been derived from the classic diagram in textbooks that shows two heterozygous parents with their four offspring, three with the dominant trait and one with the recessive trait. For identification of a dominant trait, the student applied the following inappropriate algorithm, but one which in many situations will yield the desired answer: 'If there is a mixed group of offspring, the dominant trait is that shown by the majority.' The student was unable to reach a conclusion in the computer problem because the crosses he chose gave varying results. The student's annotation of his record sheet showed the following comments:

> 'More green than blue, so green is dominant in this cross.
> 'More blue than green so blue is now dominant.'
> 'Same number of blues and greens so nothing's dominant.'

The twelve students who did not obtain the correct conclusion failed to consider alternative interpretations of their data, and so based their answer on inconclusive evidence. Some students (n = 9) who obtained the correct answer also showed similar faulty processing, basing their answer on inconclusive evidence and failing to recognise that the data they had generated were equally supportive of an alternative hypothesis. In no case were these students aware of the invalidity of their conclusions and the inadequacy of their processing.

About one third (31%) of the students who were able to produce the correct answer to the textbook problems, showed defects in their problem-solving strategies with the computer problem. Given that the students were not aware of their inadequate or invalid procedures strongly suggest a need for explicit instruction in problem solving, as has been advocated by several researchers (e.g. Reif & Heller 1982, Woods 1983).

The linkage problems

For most students, problem L1 with the missing information, posed no difficulty. A group of 48 students were reasonably confident about their answer. These students are basing their solution plan on an algorithm that assesses the numbers alone. This finding indicates a high degree of reproductive, rather than productive, thinking, a bias towards rule application, and a lack of concern for full evaluation of the data.

The computer problems L2 and L3 overall proved to be difficult for the group. Some student (n = 14) were unable to formulate a solution plan. Yet this group included students who were confident about their ability to solve problem L1, and who could routinely solve textbook problems involving two- (and three-!) point test crosses. This is consistent with the routine use of algorithms as the problem-solving strategy of these students, with little regard for the nature of the data.

A subset (n = 9) of the students could formulate a solution plan for problem L2, but failed to implement it because they had difficulty in identifying a means of generating a heterozygous cat for the test cross. This difficulty occurred because CATLAB allows students to specify cats on the basis of phenotypes only, and genotypes must be inferred. This demand brought an additional element into the problem scenario, and one that is not normally part of the textbook treatment of linkage.

The students who successfully solved problem L2 displayed appropriate skills in formulating a solution plan and in generating and interpreting the relevant data. The facility with which students achieved this varied and this was reflected in the time spent on the task.

Problem L3 proved to be tantilising to those students who successfully solved problem L2. In this problem, a variable (epistasis) that is normally treated as a separate topic, is part of the problem scenario. In consequence, the data are confounded because cats that are all-white cannot be scored for their pattern of striping. Initially, these students applied the same strategy that had worked successfully for problem L2, but found that this produced unexpected data. Some students (n = 7) gave up at this point, but many recognised the operation of the additional variable and attempted to accommodated it in their solution plan. For these students, this proved to be a learning experience that established links between two areas of their conceptual understanding - gene interaction and linkage - that had previously been compartmentalised.

One student wrote:

> 'I found this problem interesting as well as frustrating. The majority of the genetics problem on linkage we have done before, we do on the assumption that there is no gene interaction, that is, no epistatic relationships. I imagine, like m[illegible] [illegible]ost people would not even consider epistasis unles[illegible] [illegible] was actually stated in the problem. Yet, gene interaction is a part of genetic crosses, and it appears that we only consider epistatic relationships as though they were a totally separate subject.'

While the initial presentation of concepts, such as linkage, should be uncluttered by the complication of its subtle interrelationships with other concepts, learners should ultimately move to a situation which is more in accord with the complexity of the real world of genetics. In the real world of genetics, many factors must be taken into account when interpreting observations and formulating explanatory models. The focus in learning is often the integration of new material with prior knowledge. However there is also an equally important aspect of learning that involves integrating and linking knowledge that exists in separate conceptual networks. Computer-based problems can contribute to a learning setting that encourages the formation of links between concepts that are the subject of explicit investigation and other concepts that are usually presented in separate compartments. In this study, links between gene interaction and gene linkage were facilitated for many students.

Computer-based problems have been used as a complement to traditional textbook and lab. problems to extend learning experiences and contribute to students' conceptual development by identifying misconceptions (e.g., Peard 1983), and by confronting misconceptions in a productive manner (Kinnear et al. 1982).

In summary, it appears that computer-based problems of the type described above can expose students to situations that have the potential to encourage productive, rather than reproductive thinking, and in consequence, to facilitate meaningful, rather than rote learning of genetic concepts. This is consistent with the contention that "in order to learn, learners must invest mental energy in actively processing information" (Jonassen 1985). Computer-based problems can be selected to extend the boundaries of genetics problems to challenge students' understanding not only of related sets of concepts, but also their skills in integrating concepts from different compartments of genetics textbooks.

Computer based problems that require learners to generate data of their choice as part of the solution process can also be a valuable tool in examining how students select and use strategies for handling knowledge. The use of the computer in this role is a convenient complement to laboratory activities. Exposing students to problem-solving tasks of this nature can contribute to an elucidation of their problem-solving strategies, but does not appear to develop their skills in the processes of problem solving unless the experience is coupled with explicit instruction in appropriate problem-solving strategies, both in domain-independent and domain-specific contexts.

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